Brennstoffe aus solarthermischen Prozessen – Stand und Perspektiven

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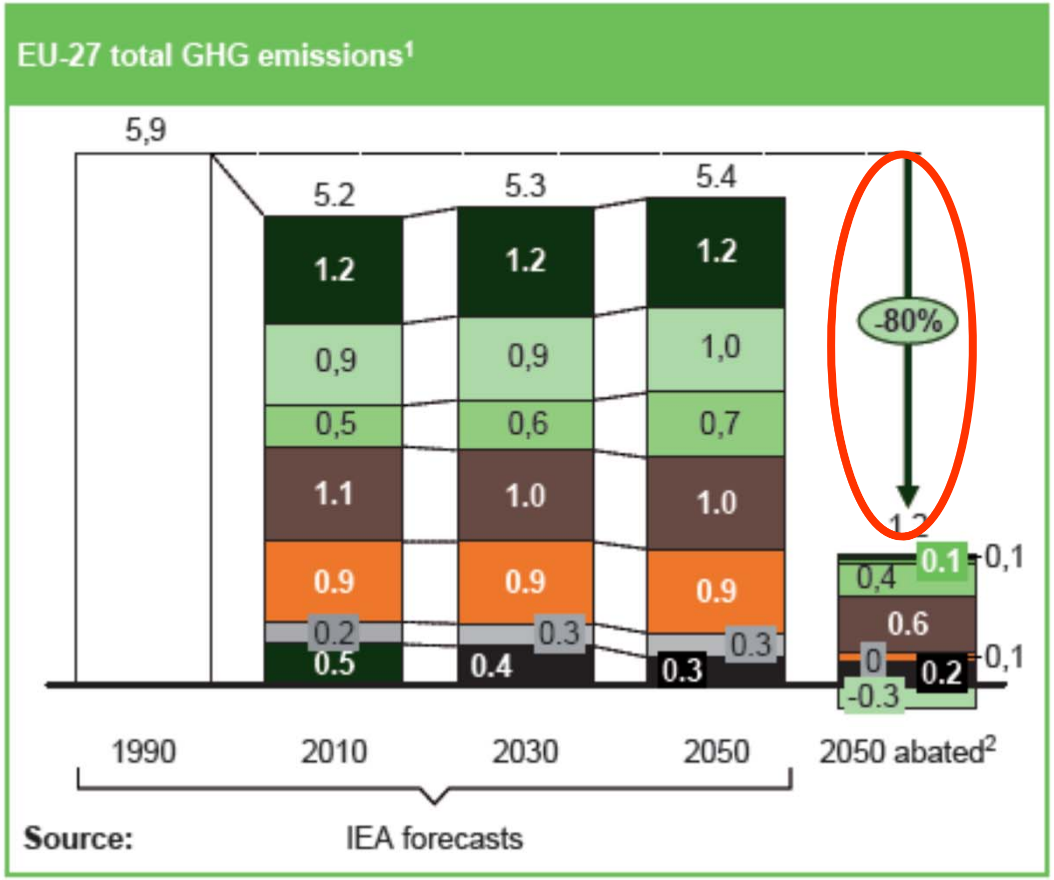
Introduction

- Background: Political, Economical, Ecological, Technical
- Concentrating Solar Systems
- Solar fuels technology scale-up
- Project examples
- Outlook

Political Drivers: Examples – EU Sustainable Energy Technology Plan (SET-Plan 2007) G7 Goals (2015)

- **Goals of the EU until 2020 (20/20/20)**
  - **20%** higher energy efficiency
  - **20%** less GHG emission
  - **20%** renewable energy
- **Goal of the EU until 2050:**
  - **80%** less CO_2 emissions than in 1990
- **G7 Goals, Elmau, Germany**
  - **100%** Decarbonisation until 2100
  - **100 bln $/year** for climate actions in developing countries, large share by industrial investment

Development of EU GHG emissions [Gt CO_2e]

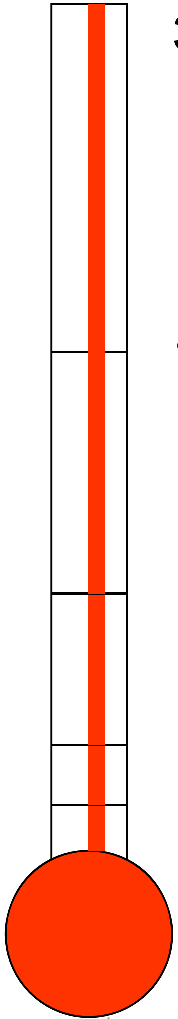


Sector	Total abatement
Power	95-100%
Road transport	95%
Air & sea transport	50%
Industry[3]	40%
Buildings	95%
Waste	100%
Agriculture	20%
Forestry	-0.25 Gt CO_2e

1 Large efficiency improvements are already included in the baseline based on the International Energy Agency, World Energy Outlook 2009, especially for industry
2 Abatement estimates within sector based on Global GHG Cost Curve
3 CCS applied to 50% of large industry (cement, chemistry, iron and steel, petroleum and gas, not applied to other industries)

SOURCE: www.roadmap2050.eu

Temperature Levels of CSP Technologies



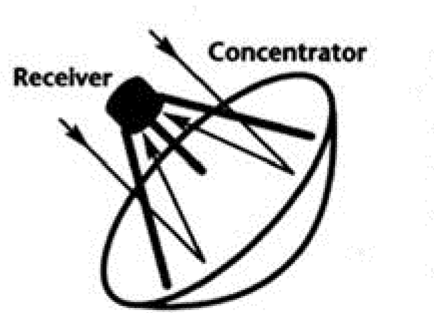
3500°C

1500°C

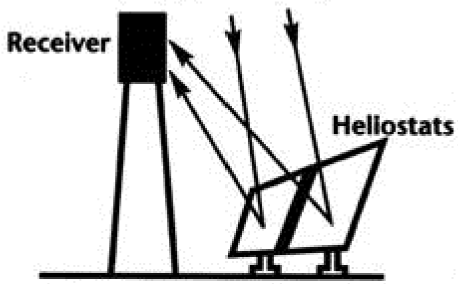
390°C

150°C

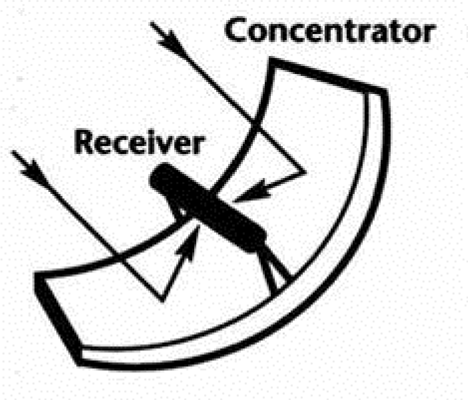
50°C



Paraboloid:
„Dish“



Solar Tower
(Central Receiver
System)



Parabolic Trough /
Linear Fresnel

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Solar Towers

http://www.ivanpahsolar.com/

-PS10, Ivanpah, Torresol
-PSA CRS, CESA-1,
-Solar-Two, Daggett,

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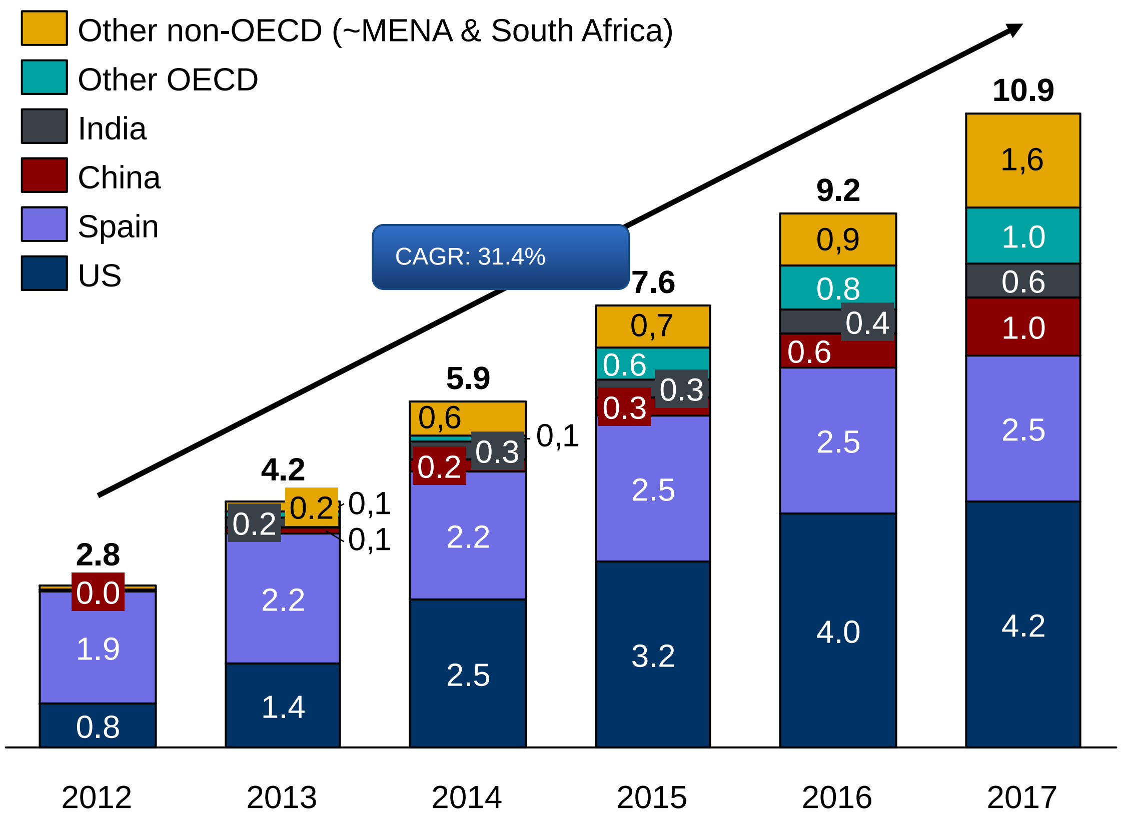
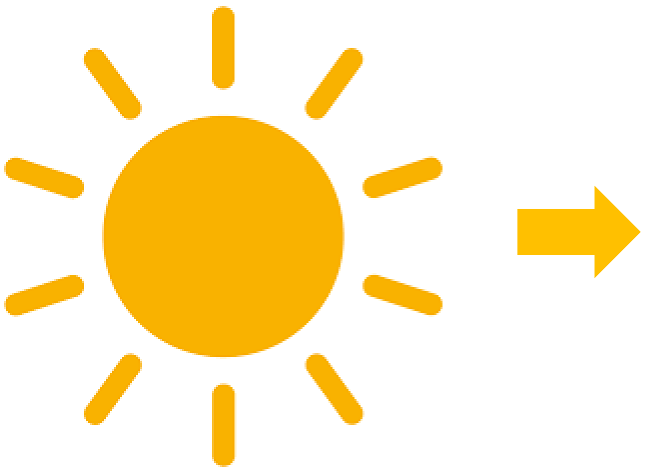
CSP Market Development according to IEA

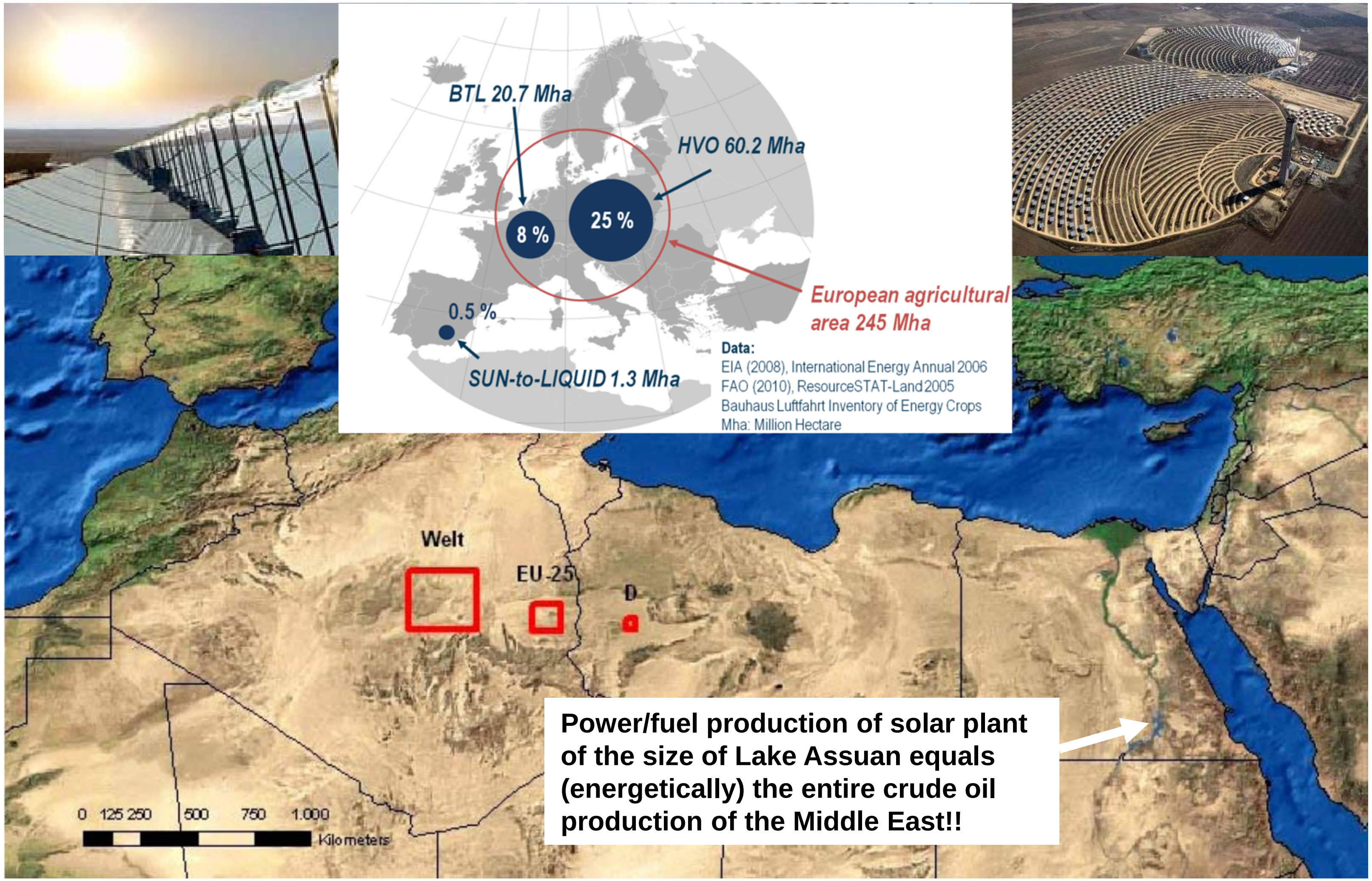


Potential Solar High Temperature Applications under Investigation



- High Temperature Electrolysis
- Water and CO_2 splitting
- Gasification of coal and biomass
- Reforming of natural gas
- Thermochemical storage
- Recycling of sulfuric acid
- Processing of ores
- Calcination / Cement production
- Ammonia / Fertilizer Production
- Metal Smelting and Recycling
- Glass production

Potential of Solar Energy



Power/fuel production of solar plant of the size of Lake Assuan equals (energetically) the entire crude oil production of the Middle East!!

Principle of Solar Fuel Production

Kohlenstoffdioxid(CO_2)
Wasser (H_2O)

Photovoltaik CSP

Windenergie Geothermie

Synthesegas (H_2 + CO)

Wasserstoff (H_2)

Transport

Flüss. Kraftstoff

z.B. Fischer-Tropsch-Anlage

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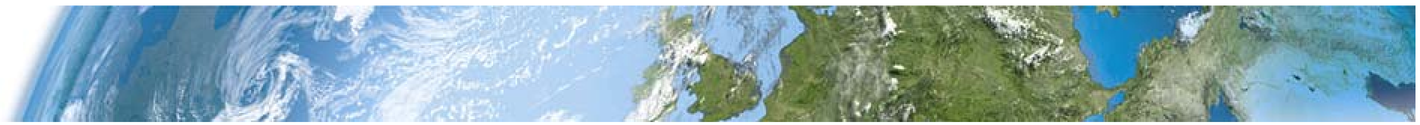
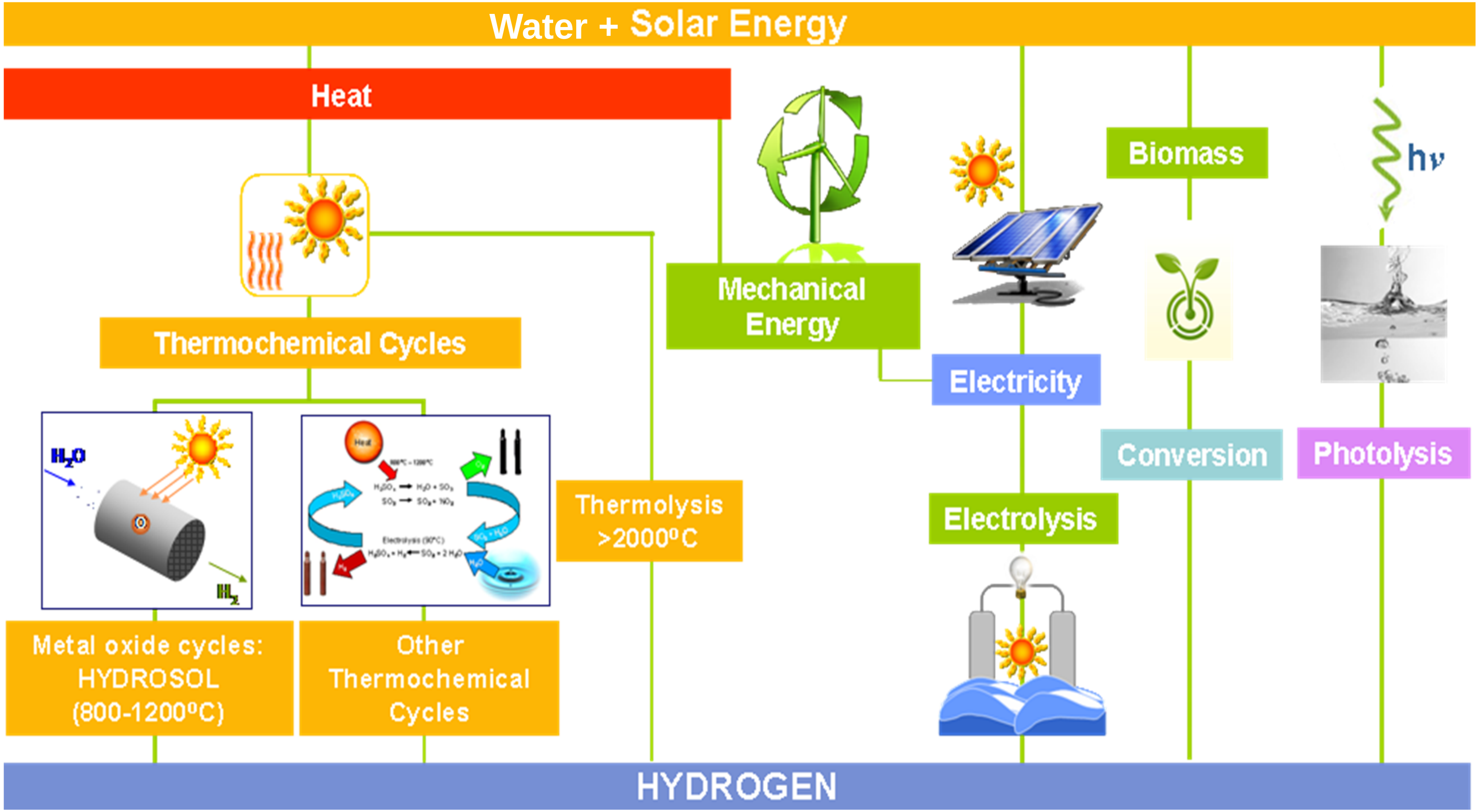


Solar hydrogen production: From raw material to fuel



Efficiency comparison for solar hydrogen production from water (Siegel et al., 2013)*

Process	T [°C]	Solar plant	Solar-receiver + power [MW_{th}]	η T/C (HHV)	η Optical	η Receiver	η Annual Efficiency Solar – H_2
Elctrolysis (+solar-thermal power)	NA	Actual Solar tower	Molten Salt 700	30%	57%	83%	13%
High temperature steam electrolysis	850	Future Solar tower	Particle 700	45%	57%	76,2%	20%
Hybrid Sulfur-process	850	Future Solar tower	Particle 700	50%	57%	76%	22%
Hybrid Copper Chlorine-process	600	Future Solar tower	Molten Salt 700	44%	57%	83%	21%
Metaloxide two step Cycle	1800	Future Solar dish	Particle Reactor < 1	52%	77%	62%	25%

**N.P. Siegel, J.E. Miller, I. Ermanoski, R.B. Diver, E.B. Stechel, Ind. Eng.Chem. Res., 2013, 52, 3276-3286.*

Technical Optimization in all Dimensions necessary

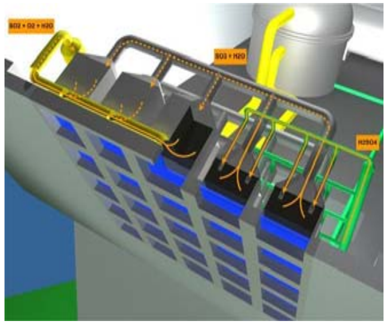
$10^4 - 10^2$ m
Solar Plant

Site

Solar field

Simulation

Environmental impact



$10^2 - 10^1$m
Receiver

Design

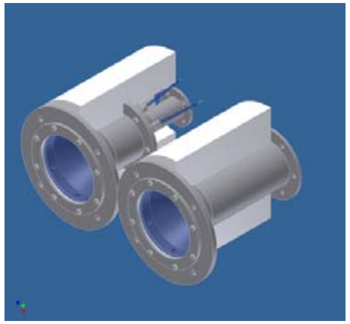
Simulation

Construction

Testing

Next-Generation-

Development



$10^1 - 10^{-2}$m
Receiver-
components

Materials

Design

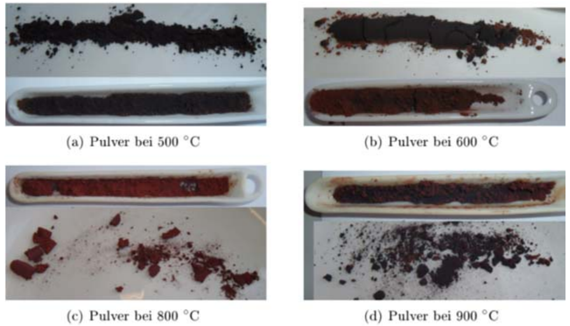
Heat and

Mass transport

Simulation

Testing and

Development



$10^{-2} - 10^{-8}$ m
Reactive Systems

Simulation

Synthesis

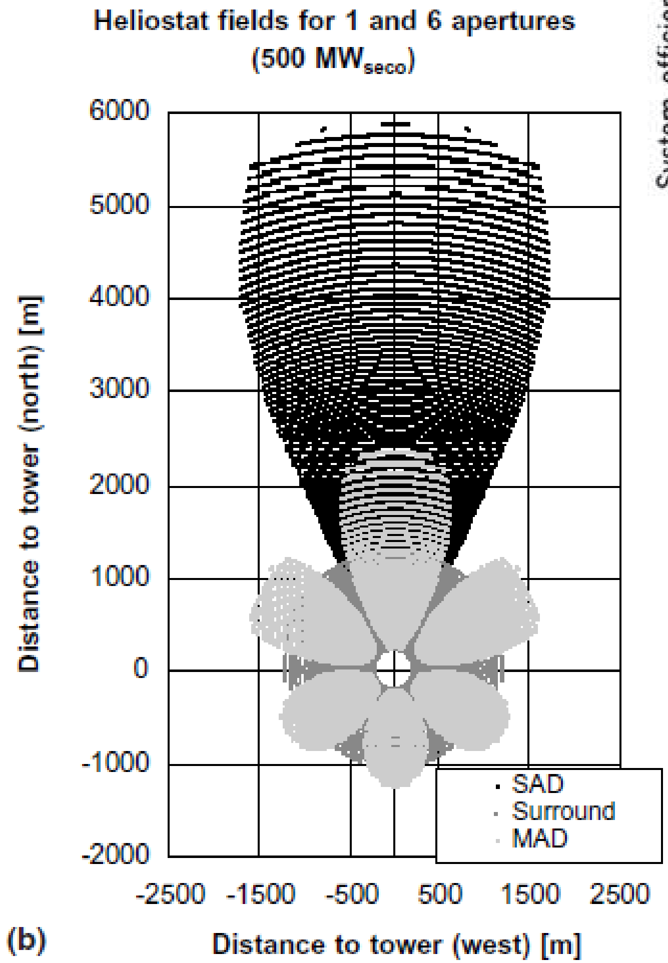
Chemical Charactristics

Physical Characteristics

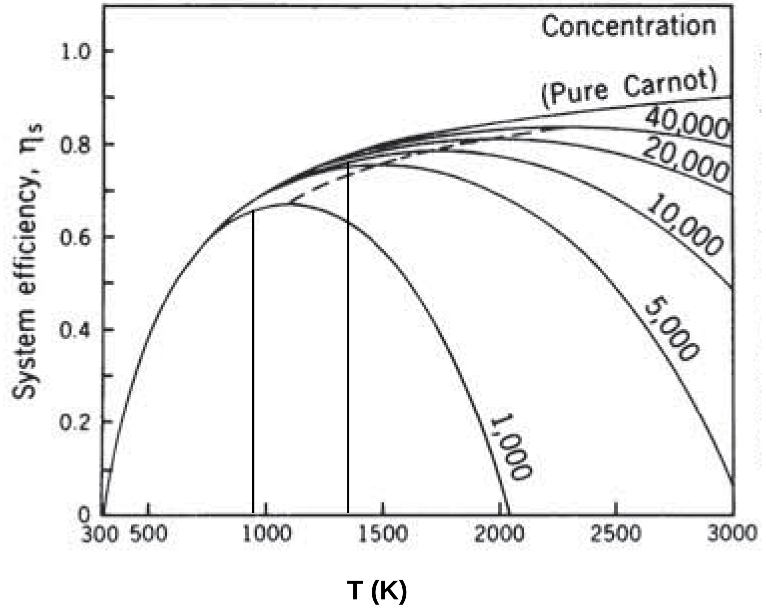
Solar Field Development

The field has to be designed for its application:

- Location
- Concentration ratio to achieve the Process temperature
- At high concentration (1000 suns) secondary optics have to be taken into account



M. Schmitz et al., Solar Energy 80 (2006) 111–120.



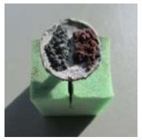
E.A. Fletcher, R.L. Moen, Science, 197 (1977) 1050-1056.

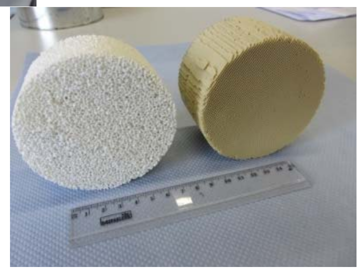
Scale evolution

TGA

Lab-scale
furnace test rig

Solar receivers





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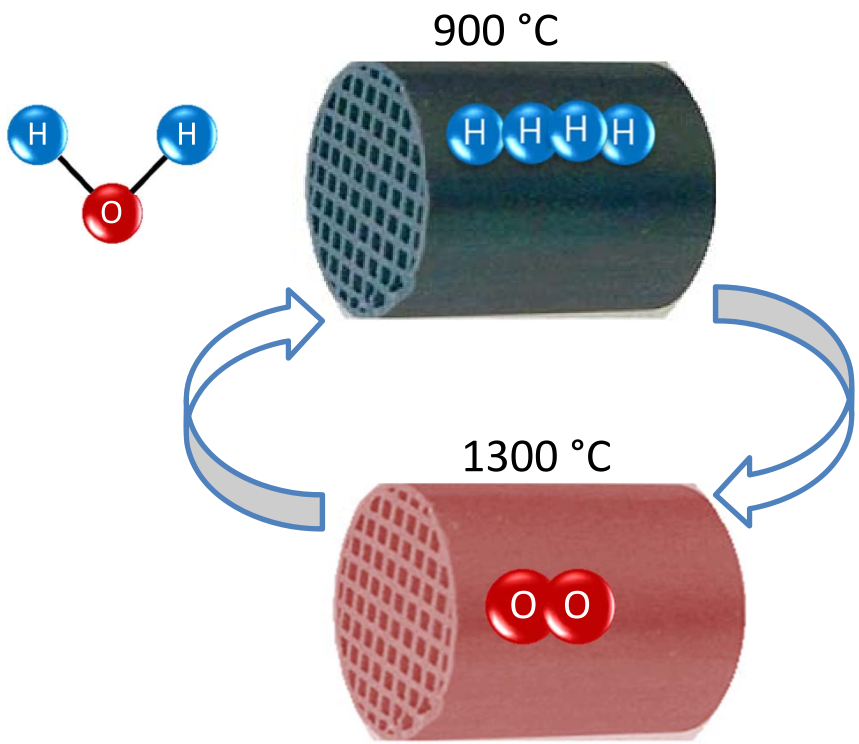
Example how a technology is developed
The HYDROSOL concept

1. Water Splitting

$H_2O + MO_{red} \rightarrow MO_{ox} + H_2$

2. Regeneration

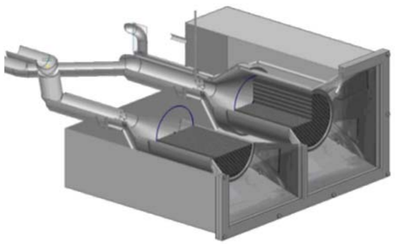
$MO_{ox} \rightarrow MO_{red} + ½\, O_2$



Net Reaction: $H_2O \rightarrow H_2 + ½\, O_2$

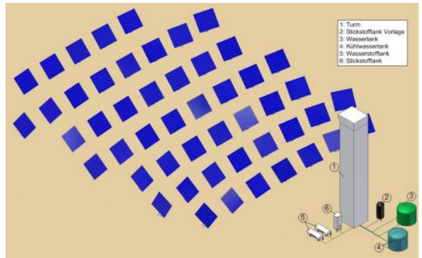
HYDROSOL Development

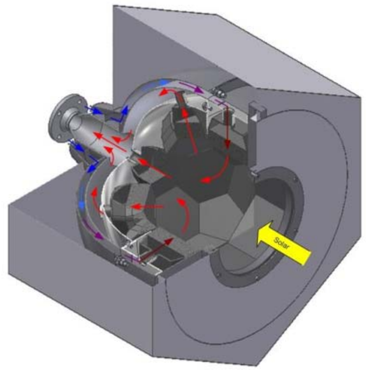
Hydrosol I
2002 – 2005
< 10 kW



Hydrosol II
2006 – 2009
100 kW

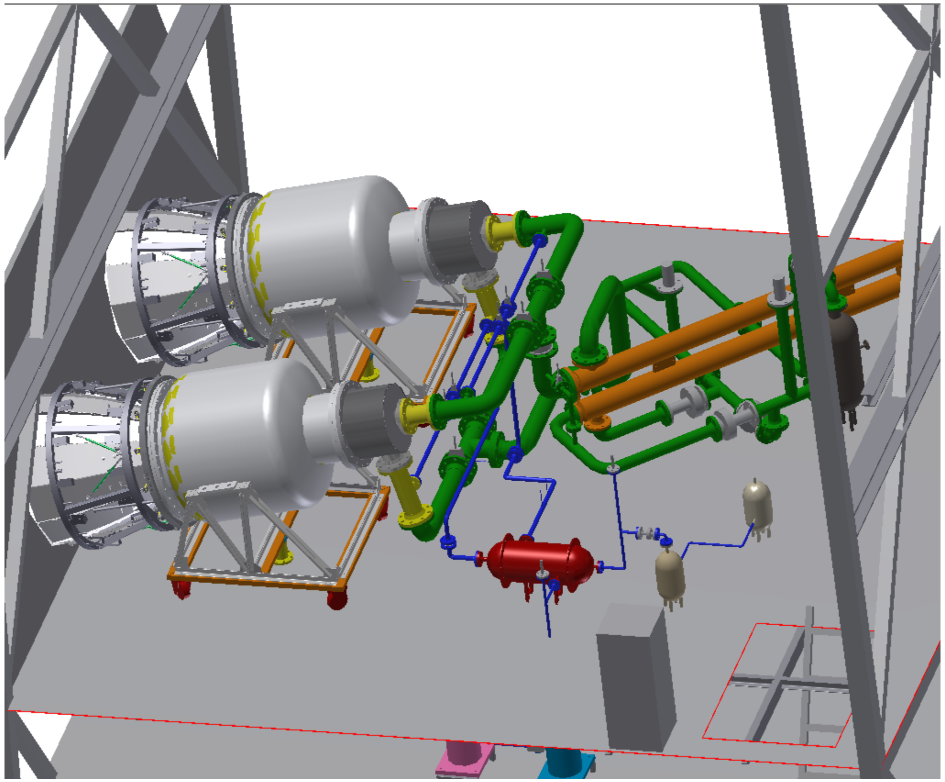
Hydrosol 3D
2010 – 2012
1 MW





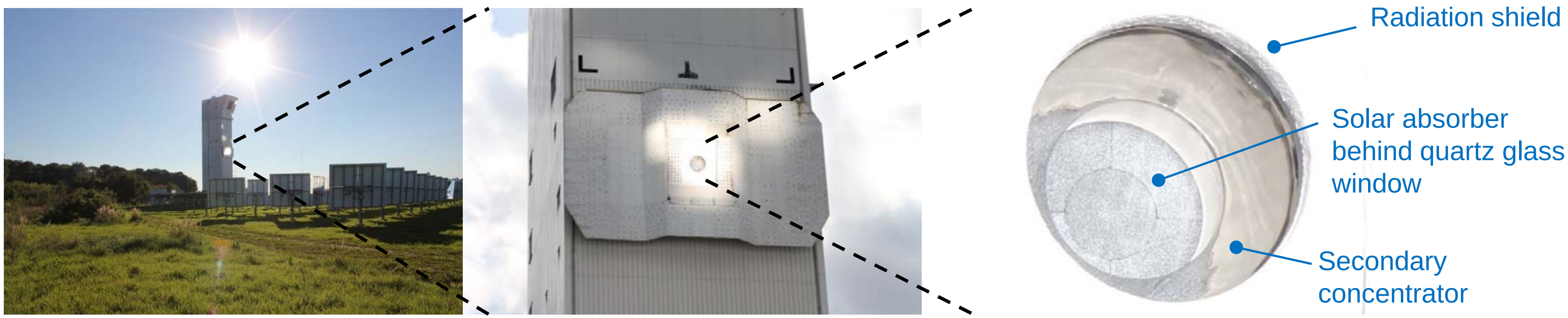
Hydrosol Plant - Design for CRS tower PSA, Spain

- European FCH-JU project
- Partner: APTL (GR), HELPE (GR), CIEMAT (ES), HYGEAR (NL)
- 750 kW_{th} demonstration of thermochemical water splitting
- Location: Plataforma Solar de Almería, Spain, 2016
- Use of all heliostats
- Reactor set-up on the CRS tower
- Storage tanks and PSA on the ground

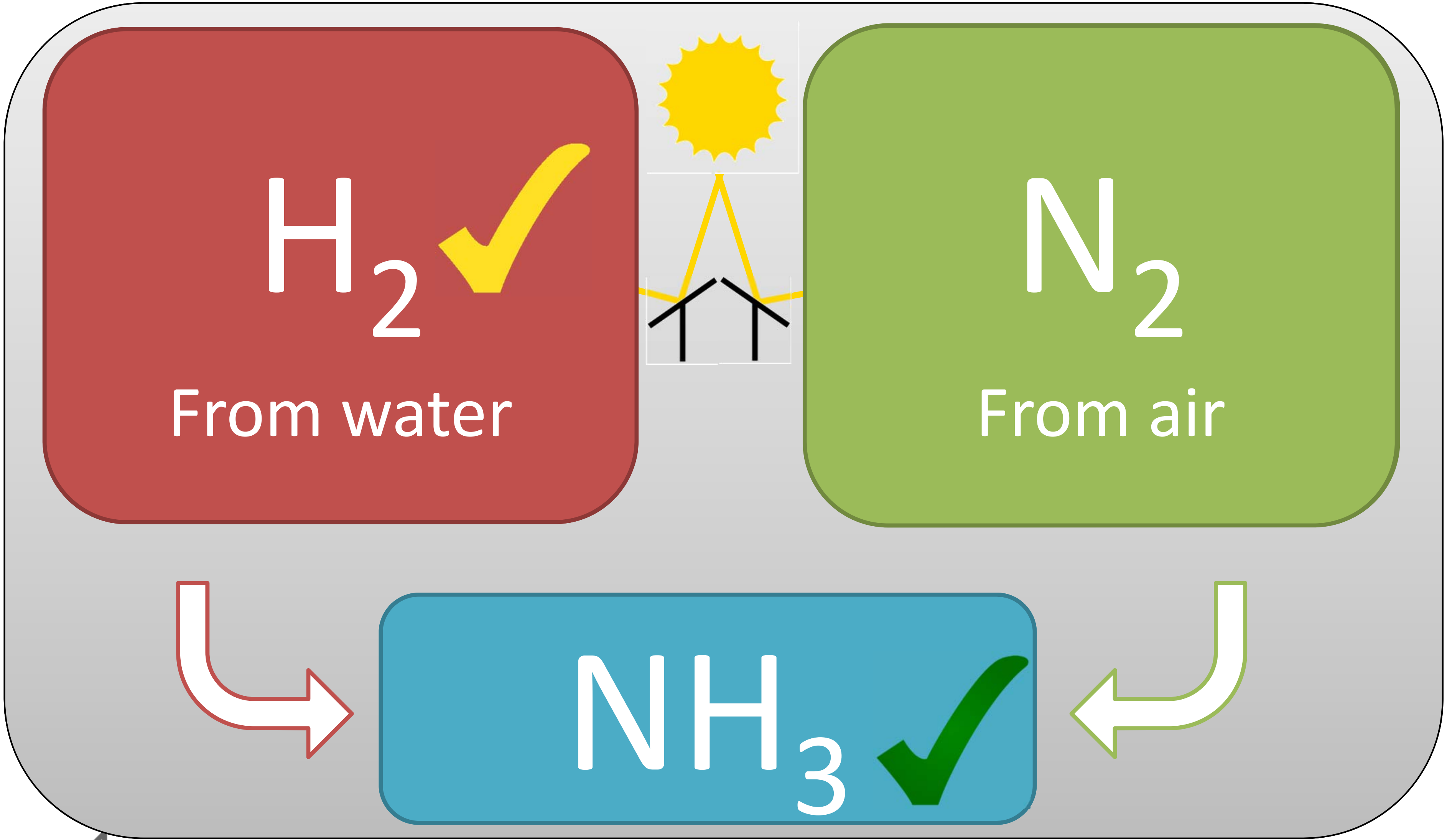


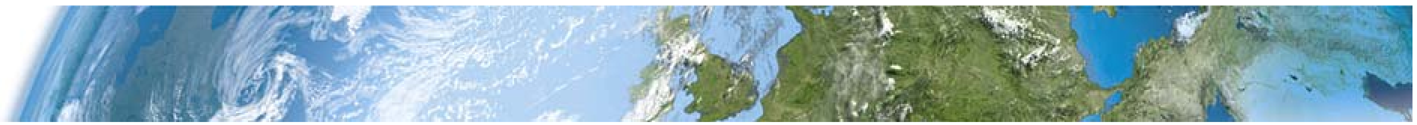
Sulfur-based thermochemical cycles for hydrogen production: on-sun operation on Solar Tower Jülich

- 07 – 09/2015: **Assembly** of pilot plant on research platform
- 09 – 10/2015: **Initial operation** with water/first test with sulphuric acid
  - Water volume flow: 600 ml/min
  - Absorber temperature: ~1200 °C @ 50 kW solar power on aperture
  - Gas outlet temperature (steam): ~1000 °C
  - **Lessons Learned**: e.g. reactor temp. too low, secondary cooling not sufficient, system is generally resistant to sulphuric acid
- 11/2015 – today: **Modification** of pilot plant/preparation of 2nd on-sun test
  - E.g. enhanced secondary cooling, changed catalyst location

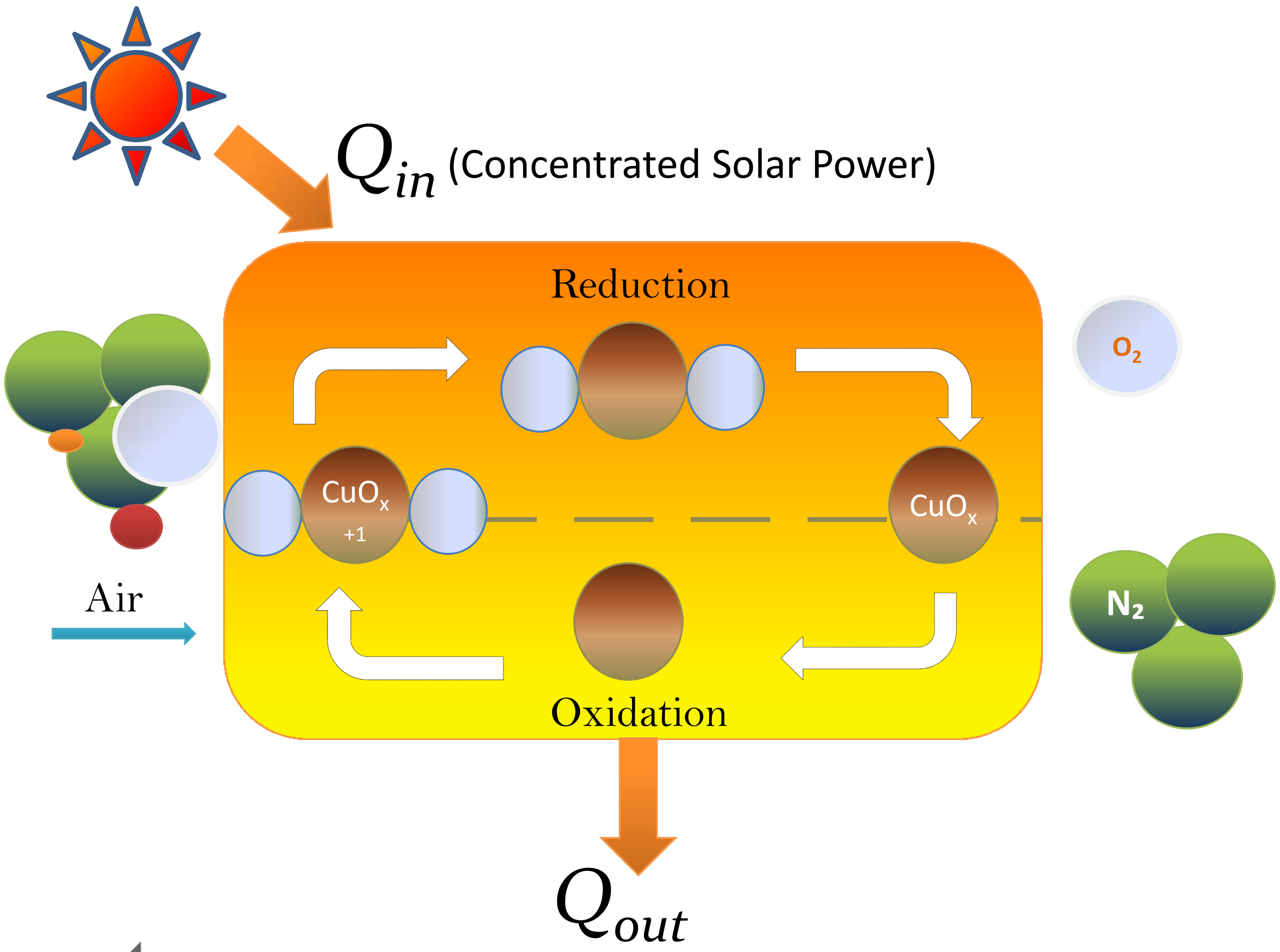


Solar Ammonia Production





Air separation based on model material: Copper oxide



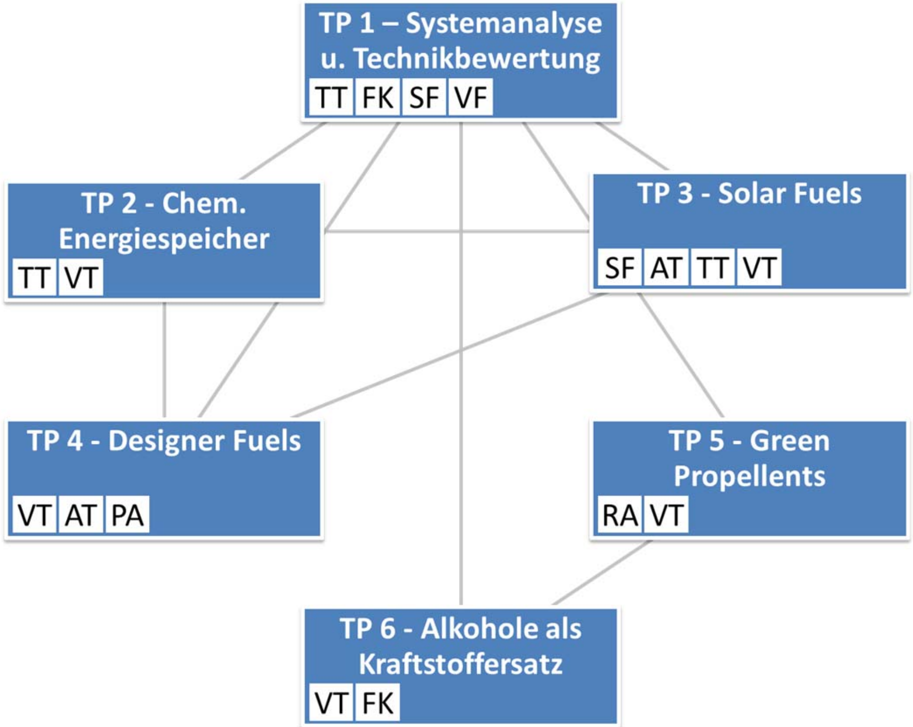
Copper Oxide

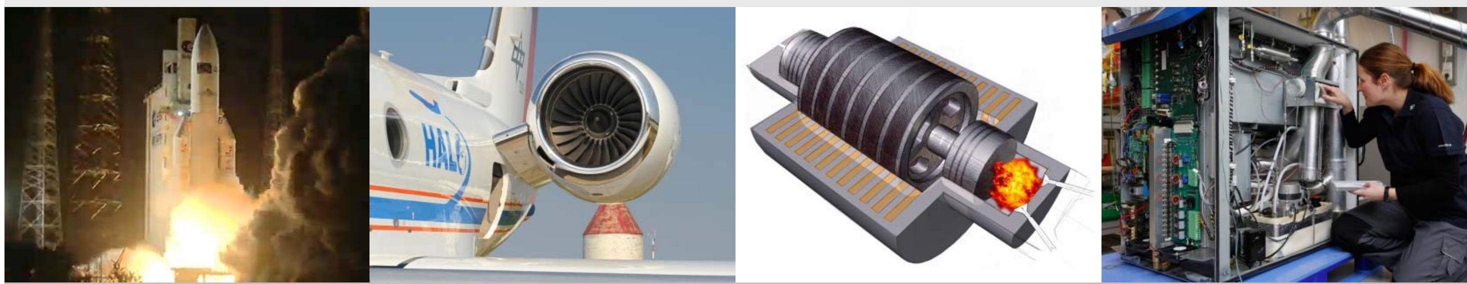
T_{red}: 880°C, T_{ox} : 840 °C

11kW/Kmol of Air

DLR Strategie-Projekt: Future Fuels – **Flüssige Energie für Strom, Wärme und globalen Transport**

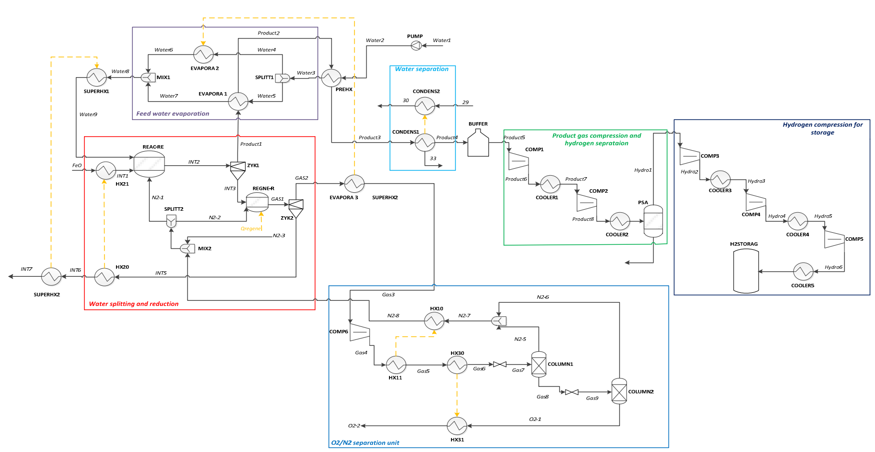
- DLR Strategie-Projekt Future Fuels vernetzt **8 Institute** in **6 multilateralen Teilprojekten**, um das Potential zukünftiger flüssiger Kohlenwasserstoffe zu untersuchen





EU STAGE-STE

- Task „Technology assessment of solar thermochemical fuel production“
  - Entwicklung von Flowsheets
  - Bewertung von Technologien für verschiedene Szenarien
  - Einordnung in die europäischen Energieprogramme (SET Plan)
  - Ökonomische Analyse

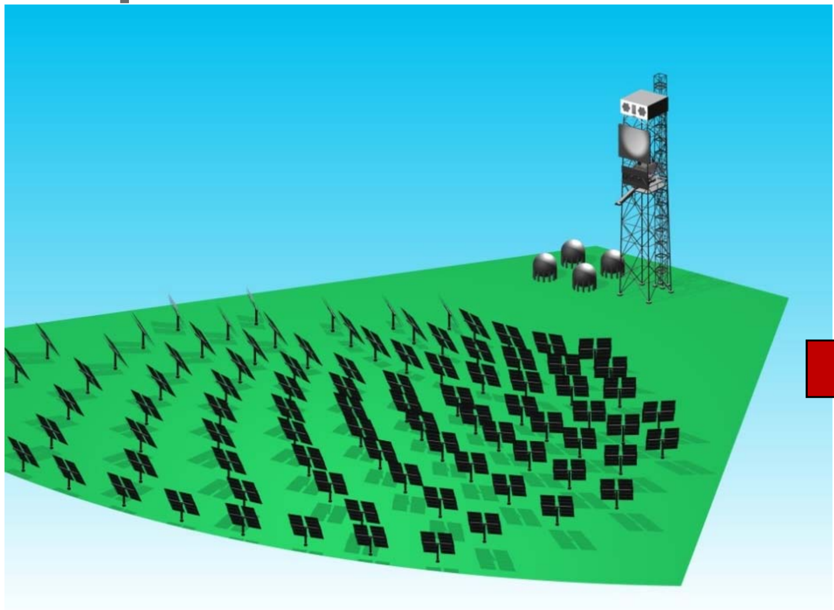


Flowsheet einer thermochemischen Wasserstoffanlage

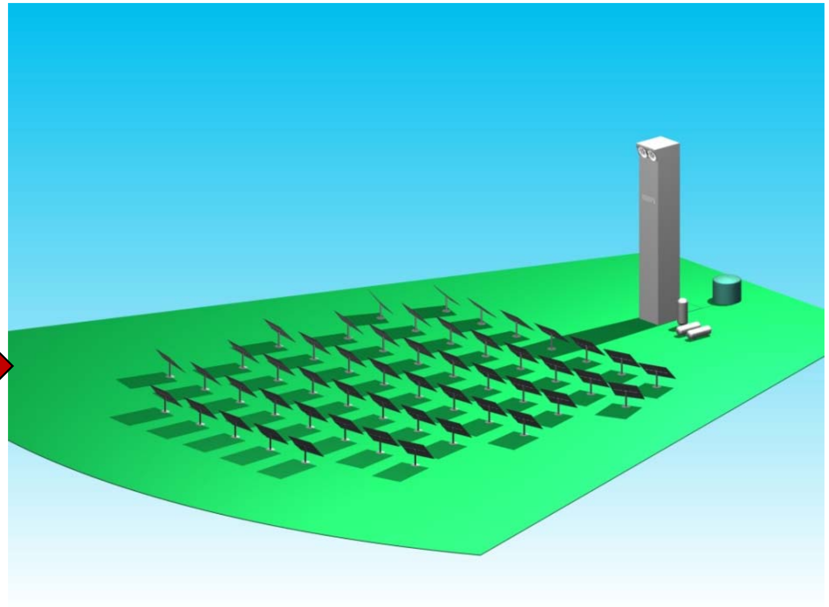
Hydrogen production scenarios

Hydrogen refuelling station	Industrial process	Single home application
-Productivity: 400 kg/day -Pressure: 700-900 bar -Hydrogen purity: 99.995%	-Productivity: 4000 kg/day -Pressure: 20 bar -Hydrogen purity: to be defined	-Productivity: 1 kg/day -Pressure: to be defined -Hydrogen puritiy: to be defined

Outlook
Specific Solar Fuel Demonstration Tower needed!



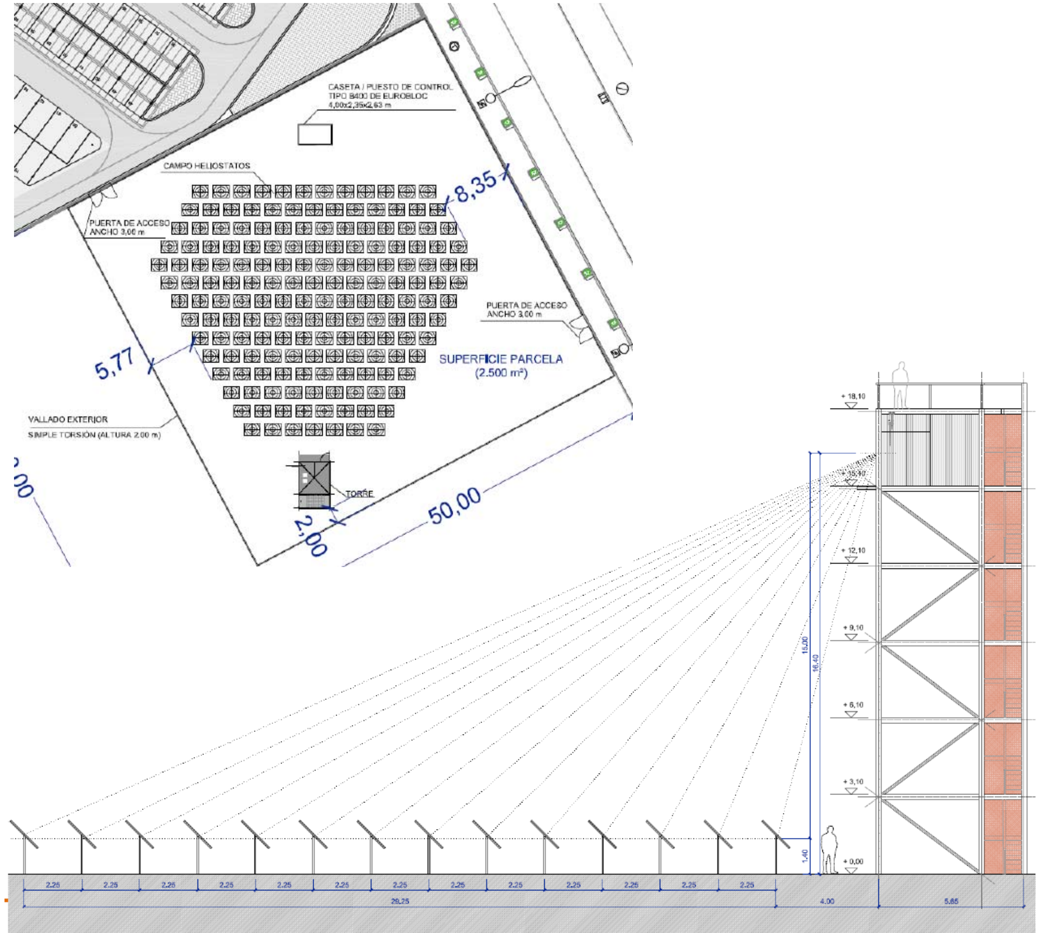
CRS Tower PSA, Spain
2008 and 2016



Solar Fuels Tower, Location?
2020

- High concentration > 1000
- Heliostats fit to receiver size
- Field control adapted to fuel production processes

EU Project Sun-to-Liquid – Current state of field design



- One unit ST44M2HEL3M purchased installed and tested
- 15m tower and target implemented for testing at representative slant range
- On-site fabrication of one curved facet from flat mirror by Rioglass (1.6x2.2 m)
- Spherical curvature with radius 50 m

Thank you very much for your attention!